AD-A247 497

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

...s average 1 hour per response, including the time for reviewing instructions, searching existing data sources, ...ing the collection of information. Send comments regarding this burden estimate or any other aspect of this ...to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson ...of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

...DATE	3. REPORT TYPE AND DATES COVERED ANNUAL 15 Jan 91 TO 14 Jan 92
4. TITLE AND SUBTITLE MULTIPARAMETER RADAR AND AIRCRAFT BASED STUDIES OF THE MICROPHYSICAL, KINEMATIC AND ELECTRICAL STURCTURE OF CONVECTIVE CLOUDS	5. FUNDING NUMBERS G AFOSR-91-0141 PE 61102F PR 2310 TA CS
6. AUTHOR(S) Dr V. N. Bringi	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Electrical Engineering Colorado State University Fort Collins, CO 80523	8. PERFORMING ORGANIZATION REPORT NUMBER AFOSR-TR- 92 0220
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Lt Col Stobie AFOSR/NL Building 410 Bolling AFB DC 20332-6448	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

After returning from CaPE we were busy installing the SUN workstations, disks, Exabyte tape readers, etc., so as to be compatible for NCAR radar analysis software. We were also busy installing software to read the PMS data tapes from the Wyoming and NCAR King Airs. While the Wyoming aircraft data is on the NCAR mass store, the NCAR data is still in the process of transfer to mass sotre. We are still to install software to read the T-28 aircraft tapes. We spent substantial time in validating and calibrating the CP-2 multiparameter radar data. Time series data from 24 August 1991 was evaluated in detail by myself and Ms. Li Liu a Ph.D. graduate student partially supported by this project. We chose time series data for evaluation since we have better handle on such data. We are pleased with the data quality from CP-2. We have chosen the cases from 26, 29 July and 5, 8, 9 August for in-depth analysis.

14. SUBJECT TERMS			15. NUMBER OF PAGES
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT (U)	18. SECURITY CLASSIFICATION OF THIS PAGE (U)	19. SECURITY CLASSIFICATION OF ABSTRACT (U)	20. LIMITATION OF ABSTRACT (U)

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February 11, 1992

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Ref: Interim Report for Proposal #90-NC-182

Dear Dr. Stobie:

Enclosed is an interim report covering the first year of the project. We are pleased with the progress so far. Dr. Jeff Caylor from UMIST joined CSU last May and he is playing a key role in the research effort. He was substantially involved in CaPE via the development of a parallel PC-based processor for CP-2 (termed Auxillary Signal Processor) for computing in real-time the propagation differential phase (ϕ_{DP}) and the copolar correlation coefficient (ρ_{HV}). Unfortunately, this system was not operational till after CaPE but a large database was obtained in coordination with the New Mexico Tech radar in August and September in electrically active storms. Examples of data from the PC-based system aligned with the CP-2 data are shown in this report.

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If you need further information please don't hesitate to call me.

Sincerely,

V. Bringi

V. N. Bringi
Professor
Electrical Engineering

VNB/br

Interim Report

Title: "Multiparameter Radar and Aircraft-Based Studies of the Microphysical, Kinematic and Electrical Structure of Convective Clouds During CaPE"

Personnel: V. N. Bringi, Professor
Dr. J. Caylor, Research Associate
Ms. Li Liu, Graduate Student Assistant

A-1

Period: 15 January 1991 - 15 January 1992

Description:

A. Summary of CSU Radar Lab Computing Environment

A brief description of the current state of the CSU hardware and software as it relates to reduction and analysis of the CAPE data set.

Hardware

The current hardware is centered around two Sun workstations: a Sparc II and a Sparc IPC which are running Unix. Both workstations are fitted with a SCSI interface bus, high density 8500 Exabyte cartridge tape drive, and high resolution 19" color monitor.

In addition, a pair of 1 Gb disk drives are interfaced to the Sparc II. One disk is configured for systems and local applications software while the second drive is reserved for project data and individual user application. The system disk is available only to the IPC via the network while the project data area is exported to a variety of machines on the CSU Engineering network.

The network also makes available general resources such as printers, plotters and other graphics devices, and 9 track tape drives. A 80486/33 MHz PC/AT clone is dedicated to CAPE analysis and is also connected to the CSU network.

Software

A variety of software has been installed. The primary radar display programs are NCAR's RDSS Perusal and Editor programs. The NCAR Zeb software is currently being installed which will allow access to the data recorded at the FOC during CAPE daily operations.

A wide variety of data analysis applications are running or currently being developed by members of the group. Such applications include radiative transfer models to be used in conjunction with the CP-2 radar data for T-39 and ER2/AMPR overflights, analysis codes for the Wyoming and NCAR King Air 2D data, plus many programs to manipulate and calibrate CP-2 radar data; both processed and time series.

In support of the above installations, system software has had to be obtained and installed such as a Fortran compiler, the Gnu C compiler, X windows library, and NCAR Common Data Format library.

CaPE Auxiliary Signal Processor for CP-2

Hardware

The auxiliary signal processor (ASP) is a PC-based system featuring a stand-alone dual channel 12 bit digitizer and an AT&T DSP32C processing card. The DSP card has available a prototyping area on which was constructed the hardware interface to the CP-2 RP-6 signal processor. The in-phase and quadrature signals were digitized in parallel with RP-6. A maximum 246 range gates are then processed in real time by the DSP32C card and recorded at 82.5 kb/sec onto Exabyte tape. A PC/AT clone (80386/20 MHz) is used to control recording and provide a user interface for configuring the DSP card.

Software

Software for the ASP was designed in DSP assembly code for time critical computations and in C for the controller/user interface program. The additional parameters made available by the ASP are differential phase, copolar cross-correlation, and doppler velocity. The doppler velocity is computed from the vertical polarized returns, the horizontal polarized returns and from the combination of the two.

Software for post-processing of the ASP data set is currently being developed which will allow integration with the data provided from the primary CP-2 signal processor.

B. CP-2 Time Series Analysis and Evaluation

On 24 August 1991 a large database of time series measurements were gathered with the CP-2 radar on a deep, squall-line system at close range. Time series analysis, while being time consuming, are ideal for data evaluation and permit post-analysis of all the multiparameter data. This is not possible with standard CP-2 products. We first tried to establish radar signatures in the rain layer covering moderate-to-intense rain rates. Two parameters which are known to estimate the rain rate are, (i) the 10 GHz attenuation, A, (indB) due to propagation, and (ii) the 3 GHz propagation differential phase (ϕ_{DP}, in degrees). Thus a scatterplot of these two variables should show a linear dependence with a slope in the 0.8-1.0 range. Fig. 1 shows such a plot where A values have been averaged over 5° intervals in ϕ_{DP}. The slope is very close to unity, and the standard deviation in A is 2.5 dB. From a theoretical analysis using gamma raindrop size distribution and equilibrium oblate shapes, the slope should be 0.8. Since ϕ_{DP} is independent of the gain, and A is dependent only on the ratio of radar constants at the two frequencies (viz., non-attenuating frequency of 3 GHz and attenuating frequency of 10 GHz), we believe that the measured slope of 1.0 versus the theoretical slope of 0.8 is due to the fact that raindrop shapes are slightly less oblate than predicted from equilibrium considerations perhaps due to shape oscillations of the large raindrops in the intense precipitation shaft.

For the same dataset, Fig. 2 shows the specific differential phase, K_{DP} ($^\circ km^{-1}$) obtained from ϕ_{DP} as the range derivative versus reflectivity (Z_H). The power-law relationship between K_{DP} and Z_H is in excellent agreement with theory. Note that K_{DP} values have been averaged over 2 dB increments in Z_H. Since K_{DP} doesn't depend on radar gain whereas Z_H does, the agreement between theory and measurements shows that the radar is accurately calibrated.

C. Example CP-2 ASP Data from CaPE

During the 1991 CaPE field project, an auxiliary signal processor was installed on the NCAR CP-2 multiparameter radar. This processor allowed measurement at S-band of the differential phase (φ_{DP}), the copolar cross-correlation ($\rho_{HV}(0)$), and the doppler velocity. Three brief examples of data from the CP-2 auxiliary signal processor are presented below.

Heavy rain

Figure 3 shows a range profile collected during a thunderstorm on 21 September 1991. The elevation angle for this beam of data is 2.55° which corresponds to a height of 1.7 km at the start of the profile and 3.5 km at end of the profile. The solid line is the differential phase while the dashed line is the correlation. This plot shows a clear increase of φ_{DP} at all ranges and a high correlation of about 0.97 both of which are consistent with propagation in rain.

Precipitation typically consists of a distribution of raindrop sizes. Since large drops are more oblate in the horizontal dimension, horizontally polarized radiation suffers a larger propagation effect than vertically polarized, especially in heavy precipitation. Of interest is the region between 40 and 44 km range where there is a very rapid increase in φ_{DP} of nearly 30°. This rate of change (K_{DP}=3.7°/km) corresponds to a rain rate of 118 mm/h which is computed using a power law function relating K_{DP} to rain rate. This high K_{DP} area is located in a region where the reflectivity exceeds 50 dBZ. Data such as these for rain give confidence that the auxiliary processor was functioning properly at all times and more importantly the data will be used to experimentally verify the theoretical relationship between K_{DP} and X-band attenuation.

Ice

Figure 4 shows a range profile collected on 20 September 1991 in the upper region of a thunderstorm. The elevation angle of 13.54° corresponds to heights between 8.9 and 15.0 km, well above the melting level at 5 km, where the scatterers can be expected to be ice.

Again, $\rho_{HV}(0)$ is >0.97 for the ranges 38 to 47 km which is consistent with the hydrometeors being composed of low density ice (e.g. crystals or snow) which has a lower refractive index than water. In the same range, φ_{DP} shows no trends and has a mean value of about -32°.

However beginning at a range of 47 km, $\rho_{HV}(0)$ begins to exhibit fluctuations and a decreasing trend. K_{DP} also shows a slight negative trend of about -0.35°/km. The reflectivity is 35-45 dBZ and there are strong gradients in the doppler velocity (>6 m/s) in this area. A preliminary hypothesis for these data is that some fraction of the hydrometeors beyond 47 km are vertically oriented (prolate) hail. This exciting result opens up possibilities of not only detecting the presence of hail but also identifying, or categorizing, the type of hail.

Lightning

Figure 5 is an example of data collected for a lightning event on 20 September 1991 during coordinated operations with the New Mexico Tech radar.

Figure 5a is a range profile at 6.06° elevation (heights 10.0-12.1 km) and shows the equilibrium conditions in the upper region of the anvil of a thunderstorm. φ_{DP} is fairly constant at -40° and $\rho_{HV}(0)$ is high. The slightly lower values of $\rho_{HV}(0)$ between ranges 95-110 km are due to the low signal to noise level associated with a reflectivity of 15 dBZ. The two arrows indicate the area where the lightning signature will appear in Figure 5b.

Figure 5b is the same cloud 400 msec later. The correlation has decreased dramatically and there are large fluctuations in φ_{DP} in the ranges 100-107 km. In addition the reflectivity has increased 30 dBZ. These polarization signatures are the return from the lightning channel. A large number of lightning events were observed during CaPE and will be analyzed in cooperation with New Mexico Tech investigators to characterize the polarization signatures of lightning and study the properties of the lightning channel and effects of cloud electrification on the hydrometeors.

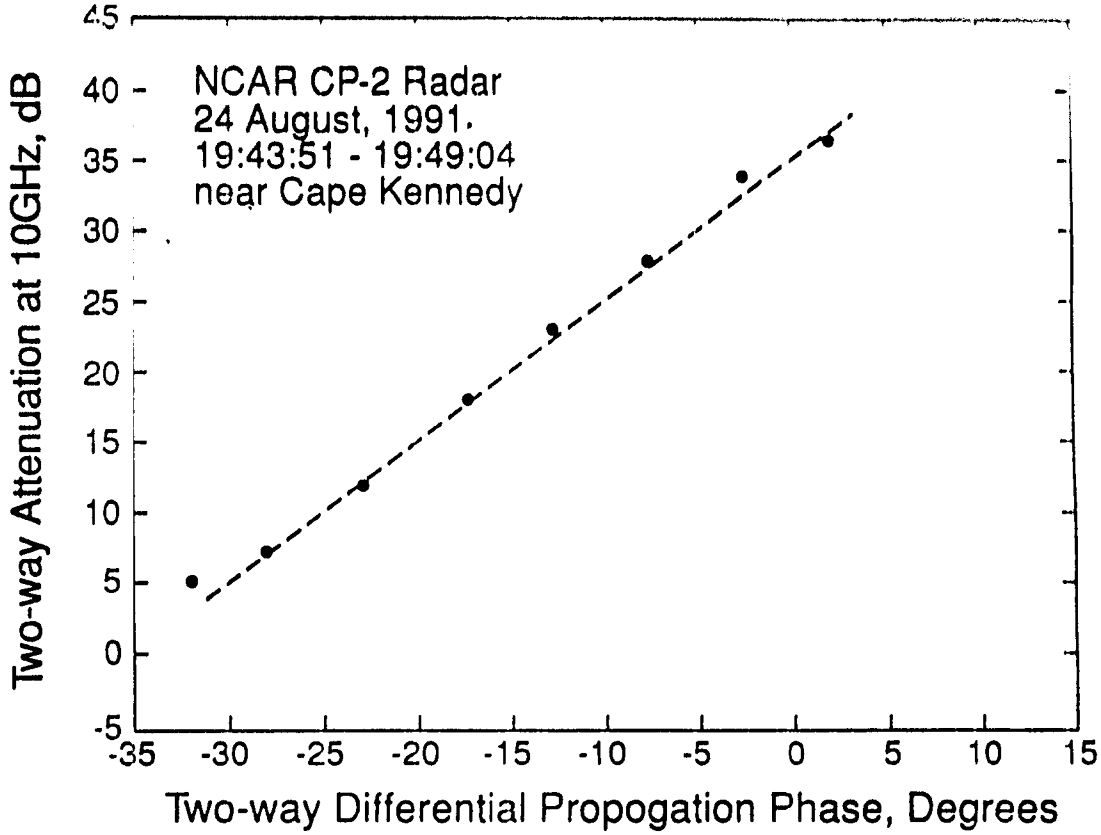

Fig.1: The mean relation between attenuation at 10 GHz and propagation phase at 3 GHz.

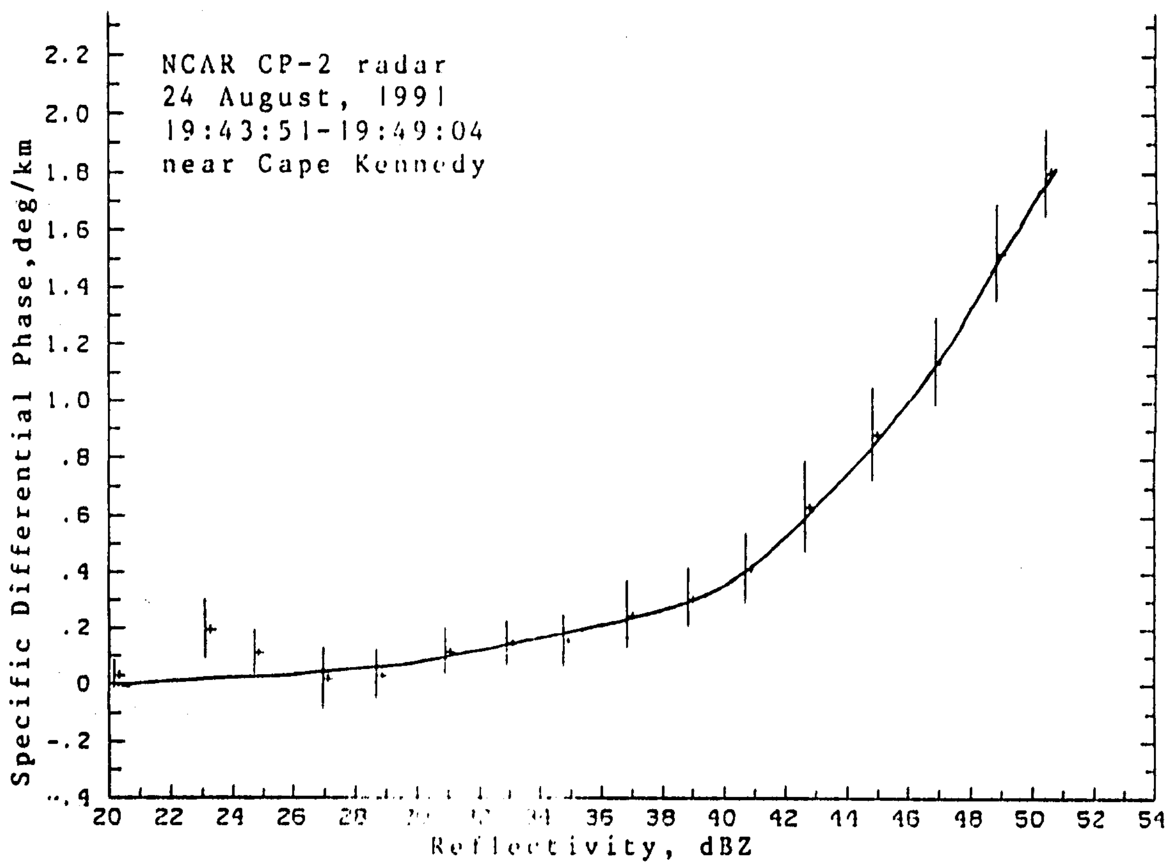

Fig.2: The mean relationship between specific differential phase and reflectivity for rainfall. Vertical bars are the standard deviation.

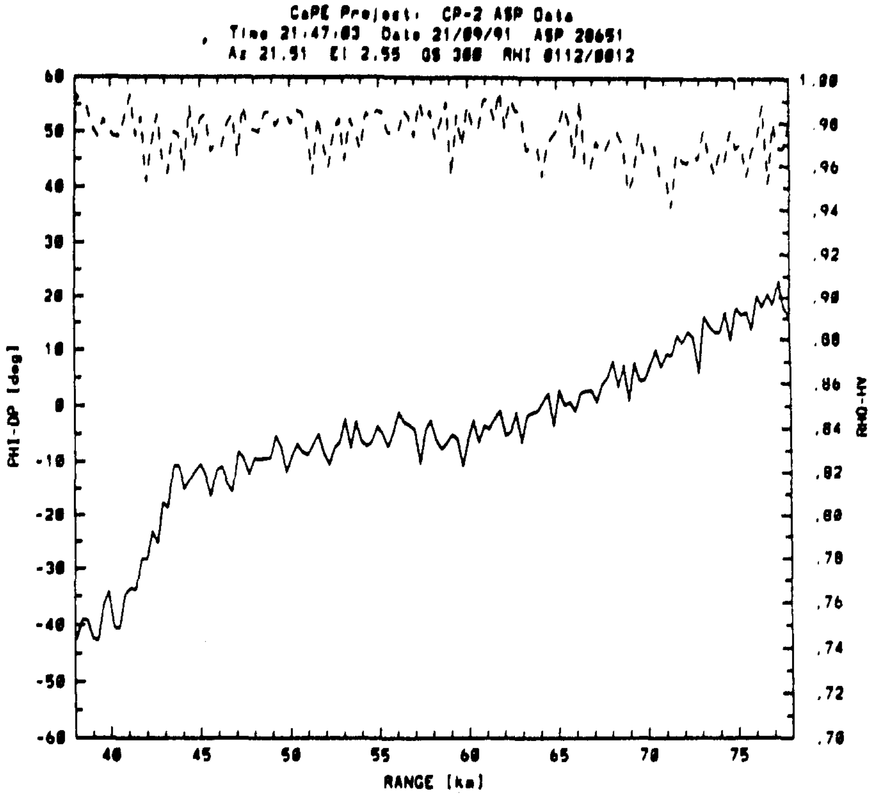

Fig 3. Range profile in heavy rain showing φ_{DP} and $\rho_{HV}(0)$ obtained with the auxiliary signal processor. The solid line is φ_{DP} and the dashed line is $\rho_{HV}(0)$.

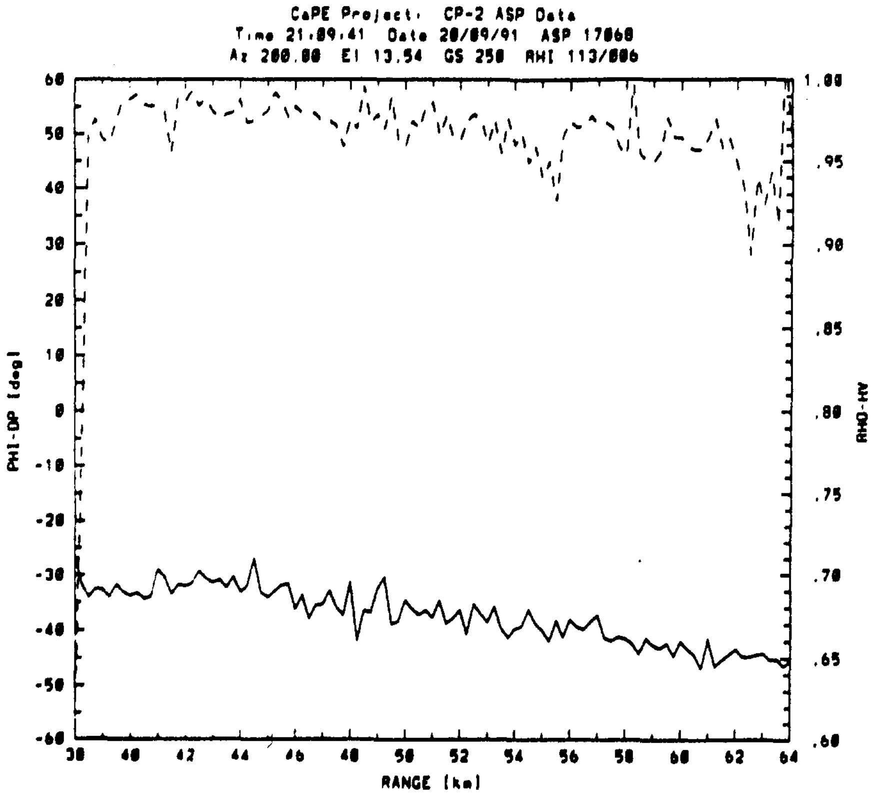

Fig 4. A range profile of φ_{DP} and $\rho_{HV}(0)$ in ice above the melting layer. The decreasing $\rho_{HV}(0)$ and φ_{DP} starting at 47 km is indicative of vertically oriented (prolate) hail.

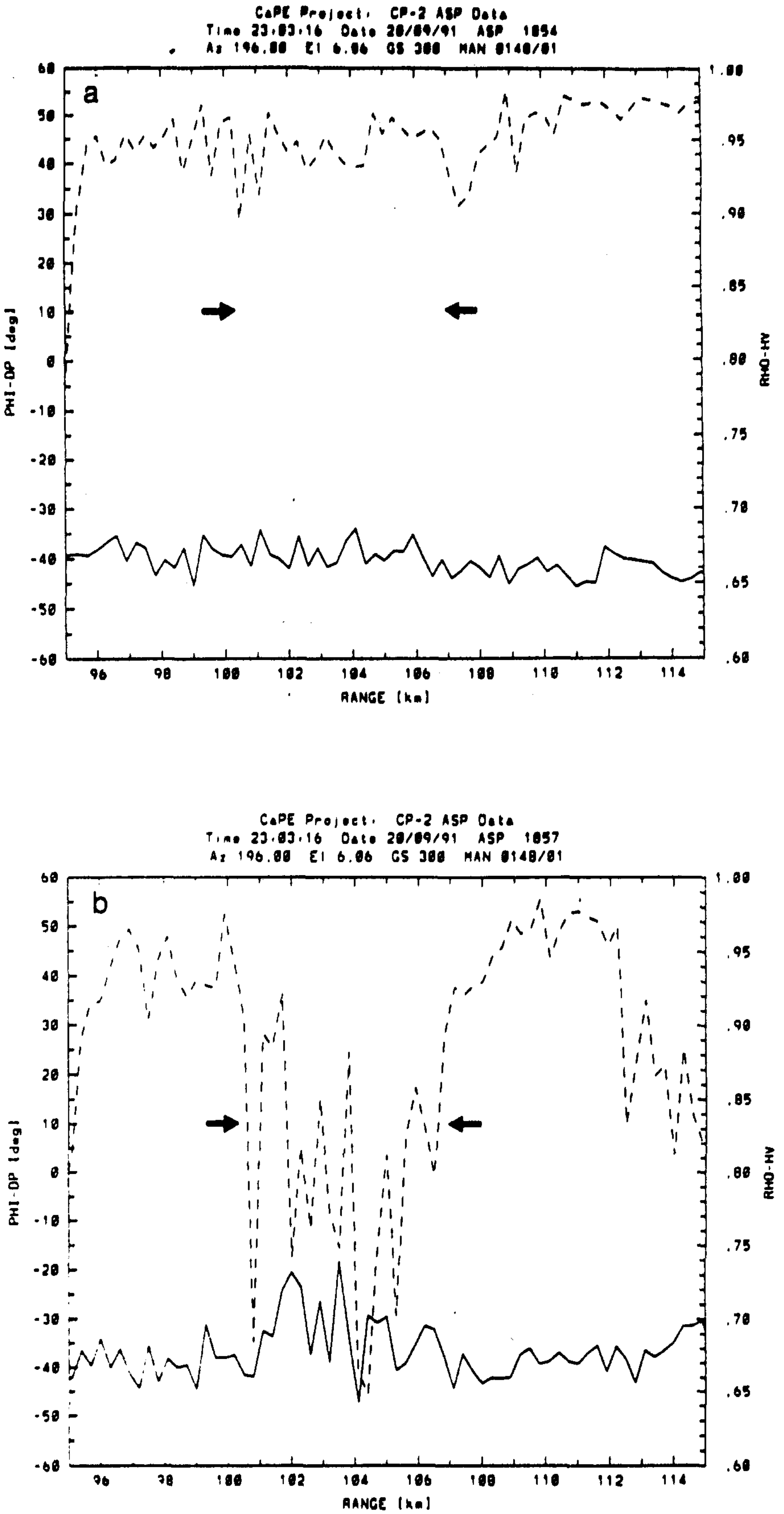

Fig 5. A pair of profiles showing a lightning event in the area between the arrows. a) The initial φ_{DP} and $\rho_{HV}(0)$ before lightning and b) the signature of the lightning channel is at ranges 100-107 km.